The Philadelphia Correspondence Schools of Foundry Practice

Dr. Edward Kirk's System of Foundry Practice

SEMI-STEEL

CUPOLA STEEL CASTINGS

MALLEABLE STEEL CASTINGS

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Semi-Steel

Semi-steel is a mixture of cast iron and steel scrap melted together in a cupola furnace, in contact with the melting fuel.

A true semi-steel is composed of 50 per cent cast iron and 50 per cent. steel, but these proportions are seldom used in making mixtures, as it has been found that a smaller per cent. of steel gives equally as good results and with more certainty of an even grade of semi-steel than the larger per cent. for castings desired to be soft and strong. But it is the common practice to call all cast iron containing steel a semi-steel.

Steel is melted with cast iron for the purpose of increasing the strength of the iron, reducing the size of the crystalline structure of the iron and making a denser and closer metal that finishes and polishes similar to steel and gives a better wearing surface. Also to reduce the porousness of the iron and prevent leakage or sweating of the metal in fittings, valves, etc.

Owing to the wide difference in the characteristics in foundry pig, made from different ores, or smelted with different fuels, pig from the different furnaces frequently give different results when melted with steel and cast iron, even when showing the same analysis of the four elements commonly analyzed for in pig. For this reason no definite per cent. of steel that gives the best results can be stated that will apply to all iron.

A founder's best guide, in making mixtures of semi-steel for the various lines of castings, is in the analysis of the iron; but this cannot always be depended upon, and more or less experimental work is sometimes necessary to obtain the best results. I shall attempt to give the best methods of doing such experimental work as may be found necessary with the least

possible chance for loss of castings and would advise that a careful study be made of the effects of the various elements or metalloids upon the iron and steel, that they may be varied to suit conditions. I would also advise a careful study of instructions for charging and melting, for the chemical component parts of a mixture may be entirely changed by improper melting and a different metal produced from that indicated by the analysis.

In the making of semi-steel mixtures a chemist is not at all necessary, for the founder, when he has learned by instructions for making mixtures, can make a mixture as accurately as a chemist, and the blast furnace analysis furnished with each car of pig is all that is necessary in figuring mixtures.

Making Semi-Steel.

Silicon, Phosphorus, Manganese and Sulphur are the four important elements or metalloids to be considered in the making of mixtures for semi-steel.

There are, no doubt, other elements in iron that may sooner or later cut an important figure in the making of this important metal, but these have not yet been discovered by the chemist, or developed by the founder, and it is my purpose to teach semi-steel making as it is made and not as it may be made. I shall therefore confine my instructions to the manipulation of these four metalloids, analysis of which are furnished with each car of iron from the blast furnace and the foundry is not put to additional expense for analysis.

Before attempting to make semi-steel, the effect of these four elements upon iron and steel should be carefully studied and fully understood, for the most important points in semi-steel making is the chemical composition of the mixture, for if this is not right, there will be no certainty as to the grade or quality of a semi-steel obtained from a mixture.

The next important point to be learned, is how to figure a mixture to give it any desired per cent of silicon, manganese, phosphorus, and eliminate sulphur.

In beginning this study, we will start with silicon, which I consider the most important element to be considered in semi-steel making.

Silicon is the controller of Carbon in cast iron, and the promoter of the absorption of carbon by steel. The per cent. of silicon in a mixture determines the form carbon will assume in the steel when absorbed and also its form in semi-steel,

A deficiency of silicon in a semi-steel mixture gives an excess of combined carbon and a hard or spotted semi-steel, for a soft, even semi-steel increase the silicon.

A very low per cent. of silicon and high per cent. of steel does not permit of the steel absorbing sufficient carbon to enter fully into combination with the iron, and a spotted or uneven semi-steel is the result. To remedy this, increase the per cent. of silicon or reduce the per cent. of steel in the mixture.

It is only in heavy castings that a one per cent. silicon mixture will carry ten per cent. steel for soft castings.

The per cent. of silicon in a mixture must be increased as the per cent. of steel is increased and a four to five per cent. silicon pig is required to carry fifty per cent. steel for soft or machined castings.

An excess of silicon reduces the strength of a semi-steel, and the lowest possible per cent. of silicon should be used to obtain a maximum strength in a semi-steel, together with other desirable properties such as hardness, softness, density and easily machining properties, all of which are controlled by silicon.

Manganese is a hardener and strengthener of cast iron and steel, and therefore has been advanced as a metal to give these properties to a semi-steel, and while it no doubt does to some extent and with certain iron impart these properties to semi-steel, its other harmful effects are so great that it should be used with caution in a semi-steel mixture.

One of its effects upon semi-steel when high is to destroy the life of the metal and make it necessary for handling the molten metal very rapidly in order to run the casting. When this occurs, reduce the manganese to a point at which the molten metal may be handled the same as cast iron, and obtain the desired strength by an increase of steel and silicon in the mixture.

Another effect of high manganese is to cause the separation of silicon in the form of silica sand, dirt, dross and blow holes. When this occurs reduce the manganese to the lowest possible point. If this does not stop the appearance of dirt in the casting, then the dirt is due to oxidization of the metal in melting, and the system of charging and melting must be changed to prevent imperfections in the casting.

Phosphorus is the life-giving element of molten cast iron and semi-steel, and the chilling effect of manganese on semi-steel may be overcome by increasing the phosphorus in a semi-steel mixture.

But while phosphorus is a life giver, it is also a weakener, and offsets the strengthening effect of manganese to so great an extent that it should not be used with a high manganese as a strength giver for the purpose of giving life to the molten metal. In such cases, it is better to reduce the manganese and in this way reduce chilling tendency of the molten metal.

It is only in case of very thin plate and light castings that it is necessary to run phosphorus as high as one per cent. in a semi-steel. And the lower it can be run, to give the necessary fluidity, the greater the strength of the semi-steel.

Sulphur should be eliminated to the fullest possible extent by the use of low sulphur iron and low sulphur coke. When this cannot be done, increase the silicon to an extent that will offset the hardening effect of the sulphur.

Never attempt to kill the effect of sulphur in a semi-steel by the increase of manganese, as this invariably produces a sluggish and dirty semi-steel.

Silicon.

Silicon is a non-metallic element of which quartz rock and silica sand are the purest native example.

Silicon is found in combination with iron in all iron ores, and also in all cast iron to a greater or less extent.

Silicon has a great affinity for iron and may be alloyed with it up to twenty per cent. in the blast furnace in smelting iron ores, and up to ninety-five per cent. in the electric furnace. When alloyed above ten per cent. it is known as ferro-silicon.

Silicon is the controlling element of carbon in semi-steel, and carbon gives to semi-steel hardness when in the combined form, and softness when in the graphite form. The per cent. of silicon in a semi-steel mixture indicates the form a carbon will assume, and by varying the per cent. of silicon a hard or soft semi-steel may be cast. A high per cent. of silicon gives a soft semi-steel, a low per cent. a hard semi-steel.

Silicon the Semi-Steel Maker.

Steel when melted in a cupola absorbs carbon from the fuel with which it comes in contact in melting to an extent that destroys its steel properties and makes it a white iron.

Steel when melted in a cupola with a low silicon iron or in excess with a high silicon iron, absorbs carbon both from the

fuel and iron and produces a harder semi-steel than the iron with which the steel was melted.

The per cent. of silicon in the iron mixture determines the per cent. of steel that can be melted with the iron to produce a semi-steel of a desired quality.

The per cent. of silicon in the iron indicates whether the carbon in a semi-steel will be in a combined or graphite state and the semi-steel be hard or soft.

Silicon controls the strength of a semi-steel by the form in which it places the carbon in the metal. Excessively high silicon in a mixture gives an excess of graphite carbon and a deficiency of combined carbon, making a weak semi-steel.

A deficiency of silicon gives an excess of combined carbon and a deficiency of graphite carbon, making a weak semi-steel, due to excessive hardness.

The proper per cent. of silicon in a semi-steel mixture gives the strongest ferous metal, either hard or soft, that can be cast from a cupola.

Manganese is classed as a strengthener of semi-steel, and phosphorus as a fluidity giver, but these metals are only auxiliaries to silicon in their effect on the semi-steel, for of what value is strength if the semi-steel is too hard for the casting, or of fluidity, if the casting has been perfectly run and is so hard or soft that it is worthless for the purpose for which it is cast?

Silicon is, therefore, the true semi-steel maker and the most important element or metalloid to be considered for semi-steel.

Manganese.

Metallic manganese is a grey-white metal, having an atomic weight 55; specific gravity, 8.00; specific heat, 1217; fusing point, 4096. When pure it is brittle and very hard, being capable of cutting glass and scratching the hardest tempered steel. It is susceptible of the most perfect polish and is not altered even in moist air at ordinary temperature.

It is found in combination with iron in iron ores, and may be alloyed with it up to forty per cent. in the blast furnace and pig iron may be purchased containing any per cent. up to forty.

Manganese has a hardening effect upon iron, as illustrated in "Spiegel iron," which contains up to forty per cent. manganese. It also is claimed to be a strengthener of both iron and

steel, and in foundry practice is used in iron as a strengthener; and also to give increased depth of chill in chilled castings.

Manganese has been found to give to steel various desirable characteristics, and for this reason was claimed to be the great semi-steel maker, the promotor of the absorbtion of carbon etc.; and a two to three per cent. manganese pig iron was advised for use in making semi-steel to give to the semi-steel a high per cent. of manganese.

Manganese in Semi-Steel Making.

To determine the exact value of manganese in semi-steel making, I have made many tests by placing various per cents. of manganese in mixtures for semi-steel. I have also visited a number of foundries in my expert work, in which high manganese was placed in the semi-steel mixture. In these tests I found that manganese was not a promotor of the absorbtion of carbon by steel from the melting fuel; that it increased the combined carbon and made a harder semi-steel, as the per cent. of manganese was increased, and to offset this hardening effect, the silicon had to be increased. The increase of silicon resulted in a dirty semi-steel, and twenty-five per cent. of the castings were found to be imperfect when machined. This trouble was overcome by decreasing the manganese.

Further tests along this line showed conclusively that high manganese in a high silicon semi-steel mixture caused the silicon to separate from the metal, and in heavy castings that cooled slowly, as high as sixty per cent. were found to be imperfect when machined, and in some of them a pure white silica sand, that had separated from the metal, was found. This separation of silicon was undoubtedly due to the high manganese, for when the manganese was reduced, it did not occur with the same metals in the mixture.

Another objectionable feature of high manganese in semi-steel is its chilling or dulling effect upon the molten metal.

In several foundries visited, in which a two to three per cent. manganese pig was being used in the mixture, the semi-steel was found to be short lived and had to be rushed to the mould to be poured before it was too dull to run the castings, and a heavy scull or ring of metal was found around the top of ladles after pouring. This trouble was overcome by reducing the manganese.

From these tests and observations, I have concluded that manganese is not the semi-steel maker that it has been heralded

to be by theoretical and book-made founders, and that its use should be restricted in castings of thin section and all castings designed to be soft and clean.

Steel is a far greater strengthener of cast iron than manganese, and when high tensile or transverse strength is required in a semi-steel increase the per cent. of steel in the mixture.

When semi-steel machined castings are found to be dirty or full of blow holes, reduce the manganese. If this does not wholly relieve the trouble, reduce the silicon.

Should the dirt and blow holes still be found, the trouble is in the melting. The metal is being oxidized in melting to an extent that changes its chemical components.

Phosphorus.

Phosphorus is a colorless waxy substance having an atomic weight 31, specific gravity, 1.83; specific heat, 1887; fusing point, 110.

Phosphorus is very volatile and to prevent it burning or phosphorizing when exposed to the atmosphere, it has to be kept under water, and when used in the arts has to be protected by a covering to exclude the air.

Phosphorus may be obtained in two varieties, the white or colorless, and red. The white, in its pure state, does not unite with iron, but the red combines readily with iron, as does also phosphoric acid, which is, to a greater or less extent, found in all iron ores.

The effect of phosphorus on cast iron, when in a molten state, is to increase its fluidity, flowing properties and life of the metal, and it has the same effect on semi-steel.

Phosphorus has a weakening effect upon cast iron and semi-steel when in excess, due to its tendency to separate from the metal in cooling, and it also increases shrinkage by keeping the metal in a fluid state for a greater length of time.

The best results are obtained in semi-steel with phosphorus .60 —.80 for thin castings, and .10 —.30 for heavy castings; but it may be found advisable to increase the per cent. of phosphorus for either class, when a very high per cent. of steel is placed in the mixture.

Pig may be obtained containing as high as twenty per cent. phosphorus, but it is better to use a lower per cent.; that is, pig containing one or two per cent. phosphorus and more of

it, as this distributes the phosphorus more evenly through a semi-steel and gives better results.

Should a semi-steel be sluggish and not flow freely in the mould, increase the phosphorus in the mixture.

Sulphur.

Sulphur is a yellow brittle substance having atomic weight 32; specific gravity, 200; specific heat, 1776; fusing point, 228 Fah.

Sulphur has an affinity for iron, and is found in many of the iron ores, and also in most of the mineral fuels with which ores are smelted. Iron takes up sulphur from these fuels in smelting, and also from the fuel when remelted in a cupola, so that none of the foundry irons are entirely free from it, and the same is the case with semi-steel.

Sulphur is a detriment in iron, steel and semi-steel in any proportion, as its effect is to harden and reduce the strength of the metal, and it should, in all cases, be eliminated to the fullest possible extent from metal for soft strong castings.

All cast iron contains sulphur to a greater or less extent, and all cast iron and steel takes up sulphur from the fuel, in contact with which it is melted in cupola practice, and it has been found impossible to obtain, in cupola melted metal, an iron, steel or semi-steel entirely free from sulphur.

Manganese is the chemical and physiological destroyer of the effect of sulphur in iron, but manganese has an affinity for both iron and sulphur, and it has been found to be uncertain in practice which one of these it will unite with, either when used in the cupola or ladle, and its use as an eliminator of sulphur has proven very unsatisfactory.

Silicon is not a destroyer of sulphur, but its effect upon iron is exactly the reverse of sulphur as a softener, and the hardening effect of sulphur in a semi-steel may be entirely overcome by an increase of silicon in the mixture.

Carbon In Steel and Semi-Steel.

In the making of steel by the open hearth and convertor processes, the carbon is all burned out of the iron along with other impurities and the iron becomes a commercially pure iron. To convert this iron into steel, the carbon is then replaced in the iron to an extent that gives the desired quality of steel. This is done by means of a high silicon iron, which is melted in a

cupola and poured into the molten iron or heated to redness and thrown into the convertor or bath of the furnace, to be melted and absorbed by the iron. Manganese and other metals are added in the same way when desired in the steel.

The per cent. of carbon restored to the iron depends upon the purpose for which the steel is to be used, and varies from .05 to .60 It is very difficult for the founder to determine which of these per cents. of carbon the steel may contain in a promiscuous pile of scrap, as this can only be determined by analysis of each piece or by an expert familiar with the appearance of the fresh fracture or purpose for which the various steels are used.

But as steel takes up carbon from the fuel in melting and the promiscous lot of steel scrap will probably average about the same in carbon, the per cent. of carbon the steel scrap may contain is of no great importance in the making of ordinary semi-steel. But the per cent. of carbon the steel scrap absorbs in melting is of the greatest importance, for steel is so totally different from cast iron, that steel floats in molten iron without uniting with it, and a low carbon steel when so mixed, may become separated from iron when cold, and retain its original properties.

If the steel has been only partly carbonized in melting, it only unites with the iron at point of contact and the result is an uneven or spotted semi-steel. To prevent this, the steel must be made to take up the same per cent. of carbon as contained in the iron mixture. This is done by the use of a higher silicon iron than would be required for casting if the iron was melted alone.

A hard or soft semi-steel of an even quality is also controlled by the carbon and an iron containing only sufficient silicon to promote the absorbtion of carbon by the steel, to a point that admits of its absorbtion by the iron, gives a combined carbon and hard semi-steel.

An iron containing a higher per cent. of silicon promotes the absorbtion of carbon to the graphite stage and gives a soft semi-steel and a semi-steel between these two extremes is produced by the varying of the silicon to increase or decrease the carbon to suit the requirements of the casting.

Points to be Considered.

To make a homogenous semi-steel, the steel must take up in melting the same per cent. of carbon as that contained in the

iron before melting, and in the same form. This is controlled by varying the silicon.

When silicon is too low the steel absorbs graphite carbon from the iron and the result is an increase of combined carbon in the mixture, and a harder semi-steel. Increase the silicon.

When the per cent. of steel is entirely too high for the silicon, the steel cannot absorb a sufficient per cent. of carbon to enter into combination with the iron and the result is a spotted semi-steel. Increase the silicon or decrease the steel.

Silicon does not promote the absorbtion of carbon by the steel beyond the point of saturation, and an excess of silicon reduces the strength of a semi-steel, the same as it reduces the strength of cast iron. When a semi-steel is soft, but not up to the required strength, decrease the silicon or increase the steel. When a semi-steel is too hard and weak increase the silicon or decrease the steel. In this case, if the steel is not excessive, increase the silicon.

Kind of Steel to Melt.

There are about as many varieties of steel as there are varieties of pig iron, all of which present different characteristics, and all of which may be found in a promiscuous pile of steel scrap.

First, we have the hard and soft steel, with carbon varying from five to sixty points.

As steel takes up carbon when melted in a cupola and a promiscuous lot of steel scrap will average about the same in carbon, this point, as a rule, need not be considered in making a mixture for semi-steel, and it is only when a special lot of scrap, known to be high or low in carbon, or a high per cent. of steel is melted, that any change may be necessary in the chemical formula of the mixture. In case of very low carbon, increase the silicon to induce the steel to take up more carbon, and make a softer semi-steel. In case of high carbon, decrease the silicon to an extent that will give a maximum strength in the semi-steel without undesirable hardness.

Besides the carbon steels, we have the alloyed steels, in which the steel is alloyed with nickel, vanadium, titanium, manganese, and other metals, to give to the steel various characteristics. These steels are not very abundant in steel scraps, and I have never met with a sufficient quantity of any one of them to make a test of their effect in the semi-steel, or learned of such a test having been made, except in melting clippings from spring steel,

which is a high manganese steel. In this case the results were stated not to be as satisfactory as with other steels. But this trouble might have been overcome by using a lower manganese pig in the mixture.

Scrap alloyed steel has the same outward appearance as other steel, and it can only be detected by analysis or previous knowledge of the steel before scrapping. When a high per cent. of it is found in the scrap, it may be tested alone or a small per cent. of it melted with other steel, in a semi-steel mixture.

Size of Steel to Melt.

The best size or weight of pieces of steel scrap to melt in making semi-steel depends to some extent upon cupola conditions and length of semi-steel heat.

For one or more charges of semi-steel, to be followed by charges of soft iron, the light or thin steel, such as boiler plate, structural steel and other light steel, should be used. For this steel melts more readily than heavy steel, and as rapidly as the iron, and is not so liable to be caught by the soft iron coming down before the steel is melted.

The same kind of steel should also be used in small cupolas and short heats, for it is not so liable to hang up, or not all be melted before the heat is melted, and a better mixture is effected for direct pouring than when heavy steel is melted under these conditions.

In large cupolas and long heats, where steel is melted throughout the heat, any sized steel may be melted, and an even grade of semi-steel obtained by drawing the metal into large ladles, or in mixing ladles.

Where these conditions exist, it is the common practice to melt steel rail and other heavy steel.

Melting Steel Turnings.

Steel turnings and borings should never be melted alone in a cupola either loose or in boxes or pipes. When charged loose, they almost entirely burn up, and when boxed, they ball up, are difficult to melt, and when melted, do not unite with iron to form an even mixture. They may be melted mixed with cast iron turnings, and as high as five per cent. of the light ribbon-like turnings may be melted in ladles, when the iron is very hot, by dropping them into the iron in a manner that will not admit of them balling up. This method is followed when it is desired to get an extra strong iron for a few castings.

The Per Cent. of Steel Placed In Mixtures.

The per cent. of steel that can be placed in a semi-steel mixture depends upon the object in view in making the semi-steel.

If the object is to reduce the cost of mixture, and make a soft semi-steel for common castings, as high as fifty per cent. of steel may be placed in the mixture, and for hard castings, as high as eighty per cent. steel has been used.

But in making a mixture for semi-steel for the various lines of castings, there are other things to be considered as well as cost of mixture, such as hardness, softness, strength, fluidity, density of the metal, etc.

It is therefore not the highest per cent. of steel that can be placed in a mixture that is of the most importance, but the per cent. that will give the best results and most satisfactory semi-steel for the work to be cast.

The per cent. that will give this result depends upon the thickness, size, weight, etc., of the casting. For a semi-steel mixture for stove plate and bench work castings would not be at all suitable for heavy castings, requiring density and strength, and a mixture for heavy castings would run entirely too hard and brittle for stove plate and bench work, even were the same per cent. of steel used in the two mixtures. So that it is the purpose of the mixture, and not the per cent. of steel, that is the controlling element.

To determine the per cent. of steel that gives the best results in the different lines of castings, a great deal of experimental work has been done. As high as forty per cent. steel has been melted in mixtures for stove plate and a soft satisfactory plate cast from it. But on further test-heats it was found that five to ten per cent. steel gave a stronger and more satisfactory plate, and this per cent. has generally been adopted by stove plate founders, using steel in their stove plate mixtures.

A great many test-heats have been made to determine the proper per cent. of steel for medium and heavy castings, but no standard has yet been adopted. Automobile cylinders of a similar weight and design are being cast in one foundry with ten per cent. steel, and at another with forty per cent. steel. Heavy cylinders are being cast with ten per cent. steel, and light ones with thirty per cent. steel, and other castings with about the same varying proportions, so there is no standard per cent. of steel that should be used.

English semi-steel metallurgists have published statements that the best results are obtained in making semi-steel by the

use of twenty to thirty per cent. steel. This may be the case with English and Scotch foundry irons, for their lines of castings, but this rule would hardly apply to this country, where the characteristics of foundry irons and also our lines of castings are more varied. The best results are only obtained by varying the per cent. of steel, to suit the iron and line of castings.

In my investigation of this matter I have found that the best results are obtained when using about the following per cents.:

Stove plate and bench-work castings, five to ten per cent.

Medium heavy castings, ten to fifteen per cent.

Light machinery and jobbing castings, fifteen to twenty per cent.

Geer wheels designed to be close and hard, twenty to twenty-five per cent.

Heavy castings, thirty to forty per cent.

Heavy hydraulic, ice machine and steam cylinders, ten to thirty per cent.

To obtain the steel effect in heavy cylinder castings and obtain a close strong metal, a higher than ten per cent. steel must be used, and when the higher than ten per cent. is used, silicon should run one and a half to two per cent. in the casting. I have produced a very close strong semi-steel for these castings using twenty per cent. steel, and also twenty-five per cent. When using so high a per cent. of steel, the mixture was made to give one and a half to two per cent. silicon in the castings, and the castings proved very satisfactory.

The following per cents. of steel are recommended: For good machinable castings, 10 to 40 per cent. steel, according to thickness of section and density required. For chill basic steel or abrasive metal, 40 to 60 per cent. steel. For white or bell iron, 60 to 80 per cent. steel.

Heat Resisting Semi-Steel.

The very best heat resisting metal for grate bars, retorts, annealing boxes, etc., is made with a high per cent. of steel, and only sufficient silicon in the mixture to make the metal close and hard, but not white.

Wrought Iron In Semi-Steel.

Wrought iron is a cast iron from which the impurities have been removed, by a process of boiling and puddling, until the

iron can be formed into a mass known as muckball. This ball when taken from the furnace in a semi-molten state, is rolled into flat pieces or bars, which are known as muckbars. These bars are cut into desired lengths, piled and heated again, and rolled into any desired shape. This process gives the iron the name of wrought iron.

The only difference in the chemical combination of this iron and that of steel is the small per cent. of carbon restored to the iron after the removal of the impurities, to convert it into steel.

Wrought iron may therefore be used in the making of semi-steel, the same as steel. The only change necessary is a slight increase in the silicon of the mixture, to make up for the lack of carbon in the wrought iron. This being the case, it is not necessary to throw out any pieces of wrought iron, that may be found in the steel scrap, as such pieces may be figured in the mixture as steel, and if of any great weight, an increase of the silicon should be made to insure them taking up the proper per cent. of carbon.

Malleable Iron In Semi-Steel.

Malleable iron is a white cast iron, from which a proportion of the combined carbon has been extracted and that remaining made to assume a different form by a process of annealing in contact with a rusted iron scale.

This process gives to the iron increased strength, ductility and softness, but does not extract from the iron other impurities found in cast iron. It should therefore be classed as a hard cast iron, in a semi-steel mixture, rather than steel.

Charging for Semi-Steel.

Steel requires a higher temperature to melt and more time to absorb the necessary heat to melt, than iron does, and for this reason it should be charged where it will receive the first heat, and most intense heat.

This point is on the coke of the bed and charges, and this is where it should be placed in the charging. Where the per cent. of steel is not large and the steel scrap light, it should be placed between the pieces of pig, and the heavy pieces of pig and small scrap, then melt together and a better mixture is effected for direct pouring.

Structural steel and other long pieces of steel should be cut into short lengths, as long pieces tend to promote bridging,

and do not give as even a mixture when extending up through the charges as when cut into short lengths and compactly charged with iron.

Large pieces of steel plate should not be placed flat on either the coke or iron in charging, for the blast cannot pass up through such plate, and in getting around it, an intense heat is frequently thrown against the lining, and the destruction of lining is very heavy.

Cut such plate into small pieces, set it on edge, or bend it in such a manner as not to obstruct the blast and heat from passing up through the stock.

The same condition, or worse, may result from charging small pieces of steel plate on top of each other in a thick layer that does not admit of the heat passing up through it, and the entire mass may be welded together in such a manner as to entirely bridge the cupola.

Two instances of this kind have come to my notice. In one it was necessary to blast the bridge out with dynamite, and the other to remove the cupola lining before the bridging could be removed. To avoid this taking place, bend the plate or roll it into tubes and mix a little coke with it in charging to keep it open, or mix the iron and plate in such a way that the heat may pass up through it evenly.

Steel is more plastic than iron when in a semi-molten state, and should be charged away from the lining as much as possible, to prevent it lodging on the lining, or adherent slag. This precaution should always be taken, and more especially with steel rails, which should never be charged flat against the lining.

The method of charging must necessarily vary with the size of cupola, size and shape of steel scrap, and per cent. of of steel melted, and to obtain the best results conditions should be studied and the method of charging varied to suit them.

One or More Charges of Semi-Steel.

When a mixture for semi-steel is not to be melted throughout the entire heat and only one or more charges are to be melted, they should be melted on the bed and following other charges, as this places the steel at the point of most intense heat when the cupola is working open and free and insures hot metal. It also enables the founder to locate his semi-steel mixture accurately and get it into the casting for which it is melted.

When melting only one or more charges, to be followed by soft iron, light steel should be placed in the mixture, as this

melts more readily than the heavy steel, and is not so liable to get into the soft iron and harden it. Heavy steel, which melts more slowly, may be hung up and dragged through the heat hardening the soft iron.

Fuel Required In Melting Semi-Steel.

A great deal has been said about the per cent. of fuel required to melt steel in the cupola for semi-steel. Many foundrymen are under the impression that a large increase of fuel is necessary in melting semi-steel, and there have been many cases in which failure to make semi-steel have been directly due to an increase of fuel to a point that produces slow melting and oxidized metal.

William Kent, M. E., in his Mechanical Engineers' Pocket Book, gives the melting point of cast iron and steel by nine eminent authorities as follows:

White cast iron, 1922-2075 Fah.

Grey cast iron, 2012-2786-2228 Fah.

Steel, 2372-2532 hard, 2732 mild, 2687 Fah.

As white iron is never used in a making of semi-steel it need not be considered. In grey iron and steel it will be observed that one authority gives the melting point of grey iron at fifty-four degrees higher than that of hard steel, and the average melting point of steel as given by these authorities is only 239 degrees above that of grey iron. This variation is so small that little attention need be given to it in cupola practice, as the steel takes up carbon from the fuel in melting, which no doubt reduces its melting point to that of cast iron, if not below it.

In my personal experience I have seldom found it necessary to increase fuel in melting semi-steel, and as the majorities of founders use an excess of fuel in melting iron, I have, in some cases, found it necessary to reduce the fuel in order to get hot metal and fast melting.

Seven to one is good melting for semi-steel, but as no two cupolas melt alike, the per cent. of fuel required is a matter that must be determined by the founder. In determining this point, his best guide is hot metal and fast melting. His cupola should melt at least eight pounds of metal per square inch of melting surface per hour, and the metal should be at a white heat as it flows from the cupola to insure a proper mixing of the steel and iron, and it should be poured hot to insure sound castings, free from blow holes and dirt, which separates from semi-steel

as it cools. The hotter it is poured, and the more rapidly cooled in the mould, the sounder the casting.

Hard Spots and Close Patches In Semi-Steel.

Hard spots or close patches sometimes found in machined semi-steel castings are always due to one of two causes: Improper chemical composition of the mixture or improper charging or melting of the metal.

In the first instance, the silicon is too low to admit of the steel absorbing sufficient carbon to enter fully into combination with the iron, and there are two grades of metal in the semi-steel without an affinity for each other. These spots are more frequently found in the shape of a close hard metal than a white metal.

Patches of this kind have frequently been found in the bore of large heavy cylinders when only a low per cent. of steel was placed in the mixture.

The iron mixtures for such cylinders generally have low silicon, ranging from .90 to 1.40 to give closeness to the metal and a high manganese, .75 to 1.20, to give strength to the iron. This formula is generally followed very closely when steel is added to the mixture, with the result that the silicon is not high enough to properly carbonize the steel for absorption. The manganese has a hardening effect on the steel, and the effect of the two together prevents a proper absorbtion of the steel, which results in hard or close patches, which, in some cases, have been attributed to changes effected in the metal in flowing up over the core.

The effect of a proper per cent. of steel on cast iron is to close up the iron, by reducing the size of crystals in the crystalline structure, and also to increase the strength of the iron, so that it is not necessary to reduce the silicon for this purpose or to use a high manganese to strengthen the iron, as both of these results are obtained by use of steel in the mixture.

For these cylinders I should advise at least two per cent. silicon in the casting and not over .30 to .40 manganese, with twenty to tweity-five per cent. steel in the mixture.

These same conditions and remedy for them applies to all machined casings in which close patches are found.

White or extremely hard spots in a semi-steel may be due to the above cause, but are generally due to oxidization of the steel in melting, caused by the steel and iron being melted too high in the cupola, by an excess of fuel, and subjected to a too prolonged

heating, before melting, or melted too low in the cupola by lack of fuel, and being struck by the blast in melting.

They may also be caused by badly rusted small steel scrap, such as boiler punchings. When using such steel, it should be tumbled and the rust removed before charging.

Hard spots also occur in semi-steel castings due to wet sand and hard uneven ramming, the same as in iron castings.

Shrinkage In Steel and Semi-Steel.

The shrinkage in steel is far greater than in cast iron, and the average allowance made for shrinkage in patterns for steel castings is one-fourth inch to the foot. This is due to the low carbon contents of the steel, and shrinkage varies with the per cent. of carbon a steel contains.

To take up this shrinkage and make sound castings, very heavy gates with sink heads and heavy risers are used to an extent. Even in steel foundries making heavy castings the remelt amounts to about forty per cent. of the heat.

But this is not the case with semi-steel, for the steel is melted in contact with the fuel in the cupola, takes up carbon, and returns to a cast iron, and in a semi-steel properly made, the shrinkage is no greater than in a cast iron containing the same per cent. of carbon and silicon, as in an iron suitable for the line of work to be cast.

There is a wide difference in the shrinkage of cast iron. A low silicon iron shrinks to a greater extent than a high silicon iron, and a heavy casting in which the iron remains fluid or semi-fluid for a greater length of time, shrinks to a greater extent than a thin casting in which the iron is suddenly cooled. This is the reason for placing shrink heads on heavy castings and churning them.

These same characteristics are found in semi-steel, and castings made of semi-steel should be treated in the same manner for shrinkage as cast iron of the same density.

Shrink and porous spots are more often due to unevenness in the pattern than to the metal, and this is always the case when the spots appear at the same place in the casting each heat. The best remedy for this is to alter the pattern. If this cannot be done, then resort must be had to risers, removing part of the metal, by coring or to a chill to cool a metal more rapidly and prevent the shrinkage or place the shrink hole in the inside, where it will not be seen or injure the casting.

Porous spots may be treated in a similar way; they may also be corked with a hammer and corking chisel when the spot is not too large.

Hard and shrink spots may appear in semi-steel castings, due to improper charging and melting, but these do not always appear in the same place.

Uneven shrinkage in semi-steel and cracks in the arms of pulleys or other castings are due to unevenness of the pattern, and the preventive measures to be adopted are the same as with iron, cast from the same pattern.

The warping or twisting of semi-steel frames, large plates, etc., is due, in most cases, to the semi-steel being too hard or close for the casting, and the shrinkage places the casting on a strain. The preventive for this is to increase the silicon to an extent that will increase the graphite carbon and give a softer semi-steel.

To straighten a casting of this kind, heat it to redness and weight it in the desired position to cool; heating relieves the strain, and the casting may be sprung into place without danger of breaking when in use.

Some years ago I met a foundryman at Seneca Falls, N. Y., who had made a large frame of semi-steel, which was slightly warped, and he undertook to use it by planing a little off at the warp point, but as soon as the outer skin of the casting was cut and strain removed at this point the casting warped at another point; when this was cut it warped at another, and he said the casting acted as if it were alive; he finally gave up the task of straightening it and scrapped the casting. Had he annealed the casting before planing, the strain would have been removed, and the second warping would not have occurred.

Semi-Steel Mixtures.

On page 22 will be found Steel Mixtures for varied line of castings.

	Silicon	Sulphur	Phos.	Mang.	Steel Scrap, Per cent.
Acid Resisting Castings	1.00 - 2.00	.05	.30 - .50	.30 - .40	50 - 60
Agricultural Machinery, Ordinary	2.00 - 2.50	.06 - .08	.50 - .70	.20 - .30	15 - 25
Agricultural Machinery, Very Thin	2.25 - 2.75	.06	.60 - .80	.10 - .20	5 - 10
Air Cylinders	1.00 - 1.75	.09	.30 - .50	.30 - .40	20 - 30
Ammonia Cylinders	1.00 - 1.75	.08	.30 - .50	.20 - .30	20 - 30
Annealing Boxes for Malleable Casting Work	.65	.05	.10 - .20	.10 - .20	50 - 60
Annealing Boxes, Pots and Pans, Light	1.40 - 1.60	.06	.10 - .20	.20 - .30	40 - 50
Automobile Castings	1.75 - 2.25	.07	.40 - .50	.20 - .30	10 - 25
Automobile Cylinders	1.75 - 2.00	.08	.40 - .50	.20 - .30	10 - 25
Automobile Fly Wheels	2.25 - 2.50	.08	.40 - .50	.20 - .30	20 - 30
Balls for Ball Mills	1.00 - 1.25	.08	.10 - .20	.30 - .40	20 - 30
Bed Plates	1.25 - 1.75	.10	.30 - .50	.30 - .40	20 - 30
Boiler Castings	2.00 - 2.50	.06	.10 - .20	.30 - .40	20 - 30
Car Castings, Gray Iron	1.50 - 2.25	.08	.40 - .50	.30 - .40	30 - 40
Car Wheels, Chilled	.60 - .70	.10	.30 - .40	.50 - .60	10 - 20
Chilled Castings	.75 - 1.25	.08	.20 - .40	.30 - .40	40 - 50
Chills	1.75 - 2.25	.07	.20 - .40	.30 - .40	20 - 30
Collars and Couplings for Shafting	1.75 - 1.00	.08	.40 - .50	.30 - .40	20 - 30
Cotton Machinery	2.00 - 2.25	.08	.40 - .50	.20 - .30	15 - 25
Crusher Jaws	.80 - 1.00	.10	.20 - .30	.30 - .40	40 - 50
Cutting Tools	1.00 - 1.25	.08	.30 - .40	.20 - .30	60 - 70
Dynamo and Motor Frames, Bases and Spiders, Large	2.00 - 2.50	.08	.40 - .70	.30 - .40	20 - 30
Dynamo and Motor Frames, Bases and Spiders, Small	2.50 - 3.00	.08	.50 - .80	.30 - .40	10 - 20
Electrical Castings	2.00 - 3.00	.08	.50 - .80	.30 - .40	10 - 20
Farm Implements	2.00 - 2.50	.07	.15 - .20	.30 - .40	10 - 20
Friction Clutches	1.75 - 2.00	.08	.20 - .30	.25 - .40	20 - 30
Furnace Castings	1.50 - 2.00	.06	.10 - .20	.20 - .30	50 - 60
Gas Engine Cylinders	1.00 - 1.75	.08	.20 - .40	.30 - .40	10 - 20
Gears, Heavy	1.00 - 1.50	.10	.30 - .50	.30 - .40	20 - 30
Gears, Medium	1.50 - 2.00	.09	.40 - .50	.30 - .40	15 - 25
Gears, Small	2.00 - 2.50	.08	.40 - .60	.30 - .40	10 - 20
Grate Bars	2.00 - 2.50	.06	.10 - .20	.30 - .40	40 - 60
Grinding Machinery	.75 - 1.00	.10	.20 - .30	.30 - .40	50 - 60
Gun Carriages	1.00 - 1.25	.15	.30 - .40	.30 - .40	20 - 30
Gun Iron	1.00 - 1.25	.06	.20 - .30	.30 - .40	20 - 30
Hangers for Shafting	1.50 - 2.00	.08	.40 - .50	.30 - .40	20 - 30
Hardware, Light	2.25 - 2.75	.08	.60 - .80	.20 - .30	10 - 15
Heat Resisting Metal	1.25 - 2.50	.06	.10 - .20	.30 - .40	30 - 40
Hollow Ware	2.25 - 2.75	.08	.50 - .70	.30 - .40	5 - 10
Hydraulic Cylinders, Heavy	.80 - 1.25	.09	.20 - .40	.60 - .80	20 - 30
Hydraulic Cylinders, Medium	1.20 - 1.60	.09	.30 - .50	.30 - .40	15 - 25
Locomotive Castings, Heavy	1.25 - 1.50	.08	.30 - .50	.40 - .50	15 - 25
Locomotive Castings, Light	1.50 - 2.00	.08	.40 - .60	.30 - .40	10 - 20
Locomotive Cylinders	1.00 - 1.50	.08	.30 - .50	.30 - .50	10 - 20
Machinery Castings, Heavy	1.00 - 1.50	.10	.30 - .50	.40 - .50	20 - 30
Machinery Castings, Medium	1.50 - 2.00	.09	.40 - .60	.30 - .40	15 - 20
Machinery Castings, Light	2.00 - 2.50	.08	.50 - .60	.30 - .40	10 - 15
Piano Plates	2.00 - 2.25	.07	.40 - .60	.30 - .40	10 - 15
Pipe	1.50 - 2.00	.10	.50 - .70	.30 - .40	10 - 20
Pipe Fittings	1.75 - 2.50	.08	.50 - .70	.30 - .40	10 - 20
Pipe Fittings for Superheated Steam Lines	1.50 - 1.75	.08	.20 - .40	.30 - .40	15 - 25
Piston Rings	1.50 - 2.00	.08	.30 - .50	.30 - .40	10 - 20
Plow Points, Chilled	.75 - 1.25	.08	.20 - .30	.30 - .40	15 - 25
Propeller Wheels	1.00 - 1.75	.10	.20 - .40	.40 - .50	15 - 25
Pulleys, Heavy	1.75 - 2.25	.09	.50 - .70	.30 - .40	10 - 20
Pulleys, Light	1.25 - 2.75	.08	.60 - .80	.30 - .40	10 - 15
Pumps, Hand	2.00 - 2.25	.08	.60 - .80	.30 - .40	5 - 10
Radiators	2.00 - 2.25	.08	.60 - .80	.30 - .40	5 - 10
Railroad Castings	1.50 - 2.25	.08	.30 - .50	.30 - .40	15 - 25
Scales	2.00 - 2.30	.08	.50 - .60	.30 - .40	20 - 30
Soil Pipe and Fittings	1.75 - 2.25	.09	.50 - .80	.20 - .30	10 - 15
Steam Cylinders, Heavy	1.00 - 1.25	.10	.20 - .40	.20 - .30	15 - 20
Steam Cylinders, Medium	1.25 - 1.75	.09	.30 - .50	.30 - .40	10 - 20
Stove Plate	2.25 - 2.75	.08	.60 - .80	.30 - .40	5 - 10
Valves, Large	1.25 - 1.75	.09	.20 - .40	.30 - .40	10 - 20
Valves, Small	1.75 - 2.25	.08	.30 - .50	.20 - .30	10 - 20
Water Heaters	2.00 - 2.25	.05	.40 - .50	.30 - .40	10 - 15
Wheels, Small	1.75 - 2.00	.08	.30 - .40	.10 - .20	5 - 15
White Semi-Steel	.90 - 1.00	.06	.50 - .60	.20 - .30	40 - 60

It will be noticed that in all the above mixtures, the manganese is low in comparison with that recommended for iron mixtures. This is due to the fact that in almost every case of complaint of dirt and blow holes in semi-steel castings that I have investigated, the manganese was found to be much higher than that given above, and a reduction of it to about these figures greatly reduced the loss of castings from this cause. Another reason for advocating low manganese is the tendency of manganese to destroy the life and flowing properties of semi-steel.

There is a wide difference in the characteristics of foundry pig used in different sections of the country, even when showing the same analysis; this is due to the presence or absence of elements not analyzed for, and it may be found advisable to increase the manganese above or reducing it below these figures. This is a matter to be decided by the founder, from a practical knowledge of the iron gained in melting and casting it as semi-steel.

Figuring Semi-Steel Mixtures.

The following table gives the shortest and most accurate method of figuring the chemical composition of a mixture from a known analysis of the pig and steel, and estimated analysis of the cast scrap, which may be estimated from the fracture indications or shape of the casting, and knowledge of the composition of the metal from which such castings are made, as indicated by our tables of semi-steel and iron castings, analysis of the castings.

This table also shows a system of keeping a record of mixtures, in charges or heats for reference. This is done by providing a printed blank, which is filled out and placed on file for reference.

Tabulation of Material to be Charged and Method of Figuring the Mixture.

Kind of Metal.	Weight Lbs.	Analysis.				Weight in Charge.			
		Sil., Per Cent.	Sul., Per Cent.	Phos., Per Cent.	Mang., Per Cent.	Sil., Per Cent.	Sul., Per Cent.	Phos., Per Cent.	Mang., Per Cent.
Steel Scrap	400	0.10	0.07	0.10	0.60	0.40	0.28	0.40	2.40
Machinery Scrap.	2.000	1.70	0.10	1.00	0.60	34.00	2.00	20.00	12.00
High Sul. Suth. .	1.600	0.70	0.10	1.50	0.30	11.20	1.90	24.00	4.80
No. 1 X........		3.00	0.03	0.80	1.25	48.00	0.48	12.80	20.00
No. 2 Foundry..	4.000	1.75	0.07	0.30	0.60	70.00	2.80	12.00	24.00
High Sil. Iron..	800	3.50	0.025	0.07	0.60	28.00	0.20	0.56	4.80
Total	10.400	......	......	......	......	191.60	7.36	69.76	68.00
Average Per Cent in Charge	......	......	......	......	......	1.84	0.071	0.67	0.65

Under analysis is placed the known per cent. of various elements in one hundred pounds of iron. The weight in charge is a multiple of this per cent.: thus, steel scrap, Si 0.10 in 100 lbs. of scrap, 400 lbs. gives weight of elements in the charge, $4 \times 10 = .40$. The per cent. in each kind of metal is carried out in this way and the total of each element in charge is divided by weight of metal in the charge. To the total weight of elements is added two ciphers before dividing; this gives per cent. and fraction of per cent.; three ciphers added gives thousandths of per cent. Thus, sul. 7.36, add three ciphers, 736000, and divide by total weight of metal in charge: $10400 \div 736000 = 0.071$. The small fraction remaining after dividing for hundredths or thousandths is not considered of importance, and the whole number nearest the figure is taken as result, which in this case is 0.071, or 0.07 per cent. Analyses of pig are made from a few pigs, taken from a carload, and only represent approximately the per cent. of the various elements in the entire carload of iron. It is therefore not necessary, or the practice, to figure on small fractions or to place odd pounds in the charges. Even 100 pounds is the rule in making charges.

In figuring the chemical composition of a mixture, take our figures on sulphur, which have been carried out, as your guide; apply this method of figuring to the other elements, and vary the number of ciphers added until you get the results indicated in the table. In the case of sulphur, three ciphers have been added; this carries it out to the thousandths of fractions. Such small fractions are not considered of importance in making mixtures, and the practice is to only add two ciphers, which gives per cent., as has been done with the other metalloids in this mixture. In case of fraction remaining is near the whole number of a per cent., it is taken as one fraction more of per cent. If not, they are not considered.

To get the desired per cent. of any metalloid in a mixture, a pig containing a higher or lower per cent. of the metalloid is used, or the per cent. of the same pig in the mixture is increased or decreased to give the desired per cent.

Cheap Mixtures.

In many sections of the country there is no market for steel scrap, and it may be purchased as low as five dollars per ton. At one foundry taking our course, they were selling it at six dollars per ton, loaded on the cars, which little more than paid the cost for loading, and they were practically giving it away to get it out of the road. In such localities a very cheap and desirable mixture may be made by melting this scrap with a cheap

high silicon Southern iron, and a superior quality of metal produced to that of the best cast iron, at a cost of from eight to ten dollars per ton, and at many of the Southern foundries at even less cost.

Such mixtures for soft castings may be made by melting fifty per cent. steel scrap with a high silicon iron and drawing it into a large mixing ladle before pouring. In this way a continuous stream may be drawn from the cupola, and an even grade of semi-steel castings produced.

For the making of such mixtures, a four to five per cent. silicon pig is required, and the per cent. of pig used in the mixture varied to suit the thickness of casting.

Cupola Lining In Melting Semi-Steel.

There has been a great deal of complaint of heavy destruction of cupola lining in melting semi-steel that is entirely uncalled for. For the destruction of lining is no greater in melting semi-steel than in the melting of cast iron, when the metal is properly charged, and the heavy destruction of lining is entirely due to improper charging and in some cases to excessive blast and the same heavy destruction would occur in melting iron alone.

In one foundry, in which the destruction of lining was so great that it was necessary to put in an entire new lining every three months, when melting only a short heat of two to three hours per day. In this case it was found that the coke and metal were being put in in such small charges that it amounted to a mixing of the metal and coke, and the cupola, with an excess of blast, had no melting zone, but was melting all the way up to the charging door, and the destruction of lining, all the way up to the charging door during each heat, was almost as great as in the melting zone of a properly charged cupola. This destruction could not be repaired as in a melting zone, and a new lining was necessary every three months.

At another foundry where a complaint of the cutting out of the lining in spots was made, it was found that steel plate was being charged in such a way that the heat from under it, in passing up, was thrown against the lining in spots with a force of a blow pipe flame and cut the lining out in spots wherever this intense heat was thrown against it. Had this cupola been charged in a way that admitted of the blast and heat passing up through the stock as it should do, there would have been no burning out of the lining in spots.

These same phenomena may occur in melting iron, and our instructions for the preservation of lining in cupola practice

should be carefully studied, that a lining may be made to last as long as possible.

Steel Lost In Melting.

There has been a variety of tests made to determine the loss in melting steel in semi-steel making; these tests have invariably shown a smaller loss in melting than in melting the same mixtures of iron without the steel. This was the case in melting both light and heavy steel, and even in melting for stove plate ten per cent. of the thin steel plate used in stove mounting, a smaller loss in melting was shown than without the steel in the mixture. This is probably due to the steel taking up carbon in melting, which increases its weight or prevents loss in weight. These tests were made with heavy and clean light scrap, free from a heavy coating of rust, although some of it was slightly rusted.

In the melting of steel for sash weights, in which case all steel scrap is frequently melted alone, I have not been able to learn of any accurate tests having been made to determine loss in melting.

These foundries generally judge their loss is melting by the amount of slag produced from different grades of scrap, when charged and melted in the same way, and pay a less price for scrap producing an excess of slag. In one case, in which tin *plate* steel scrap, from which the tin had been removed from the plate by an acid process, was melted alone, nothing but slag was obtained.

Old stove pipe and badly corroded light steel produce an excess of slag and very little metal.

Pig Iron For Semi-Steel.

Pig iron is the crudest form of iron we have to deal with, and may contain almost any of the known elements or metalloids.

Steel is an iron from which almost all the foreign elements or metalloids have been removed, and is a commercially pure iron.

We have, therefore, two distinctly different metals to deal with in combining cast iron and steel to make semi-steel. So distinctly different are these two metals that were they melted separately, poured together and cooled, they could only be found in combination to a very limited extent, at point of contact, while the main body of each retained its distinct characteristics. Were they to be stirred or mechanically mixed in a molten state, the result would be a harder metal than the cast iron, and if not

thoroughly mixed before becoming too dull to unite, a spotted or streaked metal not possessing the strength or machining properties of a true semi-steel would be the result.

Before these two metals can unite to form a homogenous new metal, they must be made of the same chemical composition, by the steel taking up silicon to promote the absorption of carbon up to the same per cent. as that in the cast iron.

The steel must take up phosphorus to the same extent as that contained in the cast iron to give to it the same degree of fluidity and flowing properties.

It must also absorb the same per cent. of manganese, sulphur and other metalloids contained in the iron before it can enter fully into combination with the iron.

All these metalloids must be absorbed from the iron by the steel, and that the resulting mixture of semi-steel may not be too hard for the work to be cast, the silicon in the pig must be higher than when cast without the steel, which contains no silicon, and the same is the case with phosphorus and manganese, which must be sufficiently high in the pig to give to the semi-steel a desired per cent. of these metalloids in the casting. The per cent. of these metalloids must also be increased as the per cent. of the steel in the mixture is increased, to insure a semi-steel of a desired quality.

The principal element to be considered in a pig for semi-steel is silicon, for this is the controlling element in semi-steel making. For any one line of castings with the same per cent. of steel, one brand or grade of pig iron containing the required per cent. of silicon to carry the steel is all that is necessary, and this may be made to carry a slightly increased per cent. of steel by increasing the per cent. of pig in the mixture.

For machine and jobbing foundries, where the castings vary widely in thickness and design, two to three grades of silicon pig should be carried in stock, that a cheap mixture may be made for any work to be cast. A good variety of pig for this purpose is one, two and five per cent. silicon; this will enable the founder to make a semi-steel of any desired degree of hardness, softness or strength, and to melt as high as fifty per cent. steel in his mixture for machined castings.

The per cent. of phosphorus a pig should contain, like silicon, varies with the line of casting, but it is only for the lightest of castings that it need be over one per cent. The per cent. of this pig may be varied in a mixture to give any desired lower per cent. in the casting.

Manganese should in all cases be low for a semi-steel, and in no case should it run over one per cent. in the pig, and even this per cent. should not be placed in a high silicon and high steel mixture. Owing to the remelt steel and old scrap in a mixture, the per cent. of metalloids in the castings are always less than in the pig.

All three of these metalloids can frequently be found in desirable proportions in one brand of pig, for a certain line of castings, but for castings of various weights and thicknesses a number of grades of pig are required to make a satisfactory semi-steel.

The total carbon in a semi-steel should not be below 3.40 per cent. When it gets below this point trouble begins. To insure this per cent. in the castings, total carbon in the pig should be about four per cent.

A good analysis for pig in making semi-steel is silicon, 2.25-3.00; sulphur, 0.01-0.30; phosphorus, 0.40-0.60; manganese, 0.30-0.50; graphite carbon, 3.40-3.60; combined carbon, 0.15-0.25.

With a pig showing this analysis, everything in the line of semi-steel castings can be made by varying the per cent. of steel, provided working conditions are favorable; that is, that the mixture is properly made and melted.

Strength of Semi-Steel.

The testing society for metals do not appear to have taken up the work of testing semi-steel for the various lines of castings, as the only reliable data I have been able to find is a few tests made with charcoal iron, to which a small per cent. of steel was added for car wheels.

The charcoal iron, to begin with, showed a tensile strength of 22,000 lbs. With this iron was melted two and a half per cent. of steel, which increased the strength to 22,467 lbs. Three and three-quarters per cent. steel increased the strength to 26,733 lbs. Six and a quarter per cent. steel and six and a quarter per cent. anthracite iron gave 24,400 lbs. Seven and a third per cent. steel and seven and a half per cent. anthracite iron gave 28,150 lbs. tensile strength. This latter test showed an increase in strength over the charcoal iron alone of 6150 lbs., and the increase would probably have been greater had all anthracite or coke irons been used, in place of the charcoal iron, as it is well known that steel increases the strength of these irons to a greater extent than charcoal irons.

Car wheels are now made almost exclusively of coke irons, a common mixture being eighty per cent. coke iron, ten per cent.

charcoal iron, ten per cent. steel, the steel being varied to suit the analysis of the iron.

The tests are interesting in showing that a very small per cent. of steel increases the strength of cast iron, which is a matter frequently doubted by foundrymen.

Outside of these tests I have no data of tests except those I have made myself and those of a few foundrymen making semi-steel under my instructions. In these tests I have found that both the tensile and transverse strength increases as the per cent. of steel is increased, and that the increase in strength varies with the analysis of the iron. A low phosphorus and manganese iron shows a greater strength and sounder castings than a high one.

These tests showed an increase of transverse strength with five per cent. steel of from 400 to 500 lbs.; ten per cent. steel, 700 to 1000 lbs., and the greatest strength for a soft machinable metal was obtained with thirty-five per cent. steel. This was 4500 transverse. For a hard metal eighty per cent. steel; twenty per cent. Bessemer pig, 4650 lbs. transverse strength. This bar was partially annealed; the same metal gave 30,760 tensile strength without annealing.

Not many years ago the government engineers rejected castings in which steel was placed for the reason that the strength was so far above that of cast iron, for which the specifications called, that it was not cast iron. They now recognize semi-steel as a metal, and in contracts recently made for semi-steel projectiles the specifications called for 30,000 tensile strength.

In another contract for gear blanks for the Panama Canal, specifications called for 3000 transverse strength in a one and a quarter inch round bar. Both of these specifications were readily complied with by the use of only a limited amount of steel in the mixture.

Holding Molten Semi-Steel for a Large Casting.

There is always a certain degree of uncertainty in successfully casting a heavy piece for which a number of hours are required to melt the iron in a small or slow-melting cupola. This uncertainty is due to the tendency of the molten iron to freeze and adhere to the bottom and sides of the ladle, and thus reduce the quantity of molten metal to the danger point of pouring the casting short, or of the metal becoming too dull in the ladle to run the casting before a sufficient amount is melted.

With the increase tendency of molten semi-steel to freeze or become dull, these difficulties increase, and the making of a semi-

steel casting requiring several tons of metal, from a small slow-melting cupola, is a problem that many founders have found it difficult to solve. But the problem has been solved, and semi-steel castings, cast from cupolas in which three hours were required to melt the semi-steel, and a perfect casting turned out.

To make such a casting, the mixture must be right to begin with, and of about the following proportions: silicon, 2.00; phosphorus, .20-.50; manganese, .10-.30. These proportions may be varied to suit the thickness of the casting, but, owing to the strong tendency of manganese to produce a chilling effect in a semi-steel, it should be kept low, and silicon, the life-giver, at the highest point that will give the desired degree of hardness or softness in the casting.

The cupola should be carefully charged and the metal melted very hot, and of an even temperature throughout the heat. A common mistake made by founders not accustomed to melting for heavy castings or long heats is to put in extra fuel in the bed to make it hold out through a long heat, and extra fuel in the charges to insure the metal being hot. No more fuel is required in a bed for a long heat than a heat of one or two hours, and no more fuel is required in the charges. In fact, the per cent. of fuel to metal melted should always be lower in long heats than in short ones.

The ladle should have an old skull to eliminate all possibility of the metal boiling in the ladle, and it should be thoroughly heated with an oil torch or a wood and coke fire just before filling, and the metal should be covered with charcoal as soon as the first tap is made and kept covered until ready to pour.

With these precautions taken, a semi-steel mixture containing twenty per cent steel has been held for two hours and a perfectly run casting turned out.

Another way in which semi-steel may be held for a large casting is to melt the iron alone in the first part of a heat, and melt all the steel for the mixture with the iron in the last three or four charges of the heat, and mix the metal for these charges with the iron in the ladle.

A semi-steel casting weighing 24,000 lbs. was recently cast in this way at the foundry of the John Hewitt Foundry Co., Newark, N. J., from a forty-two inch cupola melting from five to six tons per hour, and a perfect casting turned out, after holding the molten metal for more than two hours after the first tap was made.

This casting was a complicated cored casting twelve feet long, eight feet wide at one end and three feet wide at the other,

and varied in thickness from one and three-quarters inches to three inches, and required good fluid metal to run it.

Ferro-Alloys.

The only ferro-alloys considered of importance in the making of semi-steel at the present time are silicon, phosphorus and manganese. All these alloys or metalloids can be purchased in combination with iron in the pig, in any required per cent for semi-steel making, and it is cheaper and better to purchase them in this way than as a ferro-alloy, to be added to the metal in the cupola or ladle. It is also better to purchase a comparatively low alloyed pig, and use more of it in the mixture, than a high alloyed pig and use very little of it, as this insures a more even distribution of the metalloids and a more even grade of semi-steel.

Dr. Moldenke has published a number of tests made with ferro-titanium in the ladle, with white and gray iron, that show a marked increase in the strength of the iron, but the increase of strength was not near so great as that which had been affected by the addition of steel, at a much less cost than that of ferro-titanium alloy.

I have not learned of any tests of this alloy having been made with semi-steel.

Failure in Making Semi-Steel.

Semi-steel has many enemies among foundrymen, principally among those who have failed to produce it of a desired quality, and they are many. Their common expression is: "It does not mix; it runs full of blowholes; it does not flow, and thin castings cannot be run; it shrinks in heavy castings, forming cavities; it chills; runs spotted," etc. All of those troubles have, no doubt, been met with in making semi-steel, and all of which are due to unscientific mixing, bad melting and pouring. All these troubles, which are met with in iron foundries by inexperienced founders, are readily overcome by the experienced founder, and may be as readily overcome in melting semi-steel by the expert in semi-steel. All that is necessary to do is to see that the per cent of silicon is sufficiently high to carry the per cent of steel in the mixture. Charge in a manner that will melt the steel hot, and mix it with the iron in melting and pour it hot into a properly made and vented mold, to insure a sound casting.

Strengthening Cast Iron With Steel.

Steel is a greater strengthener of cast iron than manganese, or any other metal than can be alloyed with cast iron, and the very

cheapest strengthener that can be used. As low as five per cent. of steel will give a greater increase of strength, when the per cent of carbon is right, than either manganese of titanium alloy in the same mixture of irons. A large per cent of steel increases strength to a greater extent than a small one, and the better grades of iron show a greater increase than a poorer one. By the addition of steel to mixtures of strong cast iron, test bars have been produced, showing strength so far above that of cast iron, that castings have been condemned by government inspectors on the ground that they were not cast iron, and specifications called for cast iron.

To obtain a maximum strength, Lake Superior charcoal or other strong irons are melted with steel, but a maximum strength is not desirable for all lines of castings, for it implies a degree of hardness that is only suitable for the heavier castings. The maximum strength sought for should be that best suited for the line of castings produced, hardness and softness being considered. This may be obtained, for the general line of castings, from the ordinary foundry coke irons by the addition of steel. In endeavoring to obtain the greatest possible strength for a line of castings, a hardness or softness suitable for the castings must be considered, and the greatest strength that can be obtained when these conditions are complied with is the maximum for that line.

This is obtained by varying the per cent of silicon, to give the desired degree of hardness or softness, and varying the per cent of steel, to give the greatest strength. In doing this, the silicon should be increased to an extent that will carry ten to thirty-five per cent steel.

Cast Iron and Steel Alloy.

It is claimed by some metallurgists and chemists that cast iron and steel do not alloy to an extent that they form a heterogeneous metal. In this claim they are mistaken, as it is our experience that steel may be brought back to cast iron by adding carbon to it in a closed crucible, and a superior grade of cast iron obtained that is equal to a charcoal iron, and any degree of hardness or softness desired given to it by the per cent of carbon added to the steel. This being the case, there is no reason why cast iron and steel should not alloy when melted together, and when they fail to do so, it is due to the deficiency of carbon in the steel, and this deficiency is due to a lack of silicon in the mixture or to melting conditions.

Annealing Semi-Steel.

There is no more occasion for annealing a semi-steel casting than for annealing a cast iron one, when the semi-steel is properly made. But when not properly made or it is desired to melt an extra large per cent of steel, for malleability or strength, it may be annealed to equalize strain, straighten warped castings or give malleability. When it is only desired to relieve strain, or strengthen a warped frame, the casting is heated the same as an iron casting would be heated for the same purpose, and permitted to cool slowly in a position that will straighten it. When annealed for the purpose of increasing malleability, it must be packed in iron scale, sawdust or sand, according to the extent to which annealing is desired, and heated for a greater length of time. depending upon the object in view, which may be for a number of days, and when there are not sufficient castings to justify constructing an annealing oven, this kind of annealing had better not be undertaken.

Molding Sand.

The same grades of sand are used in making both green and dry sand molds, for semi-steel, as are used in making molds for cast iron, and the molds are made in the same way. A fine sand for light, thin castings and a coarser, open sand for heavy casting.

Cupola Steel

Cupola steel is a new metal, drawn direct from the cupola and cast. It is a higher carbon steel than open hearth or convertor steel, and for many purposes is a superior metal to either of these metals.

This steel is made by melting a high per cent of steel with a low per cent of pig or cast scrap in a cupola. In the melting, the steel takes up carbon from the melting fuel, and comes back to a white iron, but owing to the impurities having been removed from the steel in the process of steel making, is a purer metal than common white cast iron, which gives to it greater strength and wearing properties, and also greater heat resisting properties, which fits it for the parts of machinery requiring hardness to resist wear and strength to resist breakage, and also for heat-resisting castings, such as annealing boxes or pots, retorts, grate bars, etc.

To soften this steel for machining, it is annealed the same as convertor and open hearth steel castings are annealed. The success of this operation depends to some extent upon the mixture, which must be made to hold the carbon, phosphorus and sulphur at a low point. This is done by using a low silicon, sulphur and phosphorus iron in the mixture. When these three metalloids are kept at the proper point, a soft, strong metal is produced by annealing.

Mixtures.

In making this steel, a great deal depends upon the mixture to produce a low carbon steel, for if the carbon is too high in the mixture, it does not anneal to give the full strength of the steel, and is more difficult to anneal for machining.

The best results have been obtained from the following analysis of the mixture: silicon, .80 to 1.25; sulphur, .30 to .40; phosphorus, .15 to .30; manganese, .80 to 1.25; steel, 75 per cent. The silicon is varied to suit the thickness of castings, a higher silicon for a light casting, and the low silicon for heavy ones.

For chilled basic steel or abrasive metal the following analysis of mixture is recommended: silicon, 1.00 to 1.50; sulphur, .08 to .30; phosphorous, .20 to .40; manganese, .80 to 1.25; steel, 40 to 60 per cent. For white or bell iron, steel 60 to 80 per cent. with the above analysis.

Plow Points and Mould Boards.

The chilled basic or abrasive metal would seem to be an excellent metal for plow points or mould boards, but it has been found that this metal does not scour well in all kinds of earth, and I would advise a lower per cent of steel for these castings. The best results in this respect so far reported have been with about the following analysis: silicon, 1.00 to 1.50; sulphur, .20 to .30; phosphorus, .25 to .40; manganese, .20 to .40; steel, 20 to 25 per cent. The steel in this mixture acts as a strengthener and also gives chilling properties to the iron.

Charging and Melting.

Having the mixture for steel castings, it is only a matter of charging and melting. To insure a hot fluid steel from the start, a two or three inch higher bed should be put in than when melting iron. The steel should be charged first, and the pig on top of it. No cast iron scrap should be charged for a steel mixture. In melting such a large per cent of steel scrap, care must be taken in charging to charge the steel in such a way as to admit of the flame and heat passing up through the charge, and prevent caking or welding together of the steel, as is liable to occur in melting steel plate if one plate is laid flat on top of another. To prevent this occurring, bend the plate before charging, or charge the gates and remelt steel scrap between the plate, or place a little coke between them to keep the charge open. Large pieces of plate steel should never be charged in a cupola without bending or rolling up, for they prevent the heat passing up freely through the stack before melting, and frequently throw it against the cupola lining in such a way as to cut it out very rapidly. When these precautions are taken in charging, the destruction of lining is no greater in melting steel than in melting iron, and there is no difficulty in getting the steel mixture hot and fluid. Care must be taken to not use too great an amount of coke to keep the

charge of steel open, for an excess of coke causes slow melting. Should this occur, coke may be reduced in the bed or charges as indicated by the melting. The pig should be broken into small pieces, not less than four pieces to the pig, and evenly distributed over the charges of steel. This gives a better mixture and more even steel than when the pig is charged in large pieces, or thrown in a pile in one part of the cupola. When charged and melted in this way the steel may be drawn and poured as fast as melted, and a mixing ladle is seldom necessary.

Ladles for Steel.

For small work the regular foundry hand or bull shank ladle may be used and steel poured over the lip of the ladle, but a deep, narrow hand or bull ladle is better, as it exposes less surface of molten metal to the air than the flat, wide mouth foundry ladle, and reduces loss of heat from the steel before pouring. If new ladles are provided for handling steel, hand ladles should be six to seven, and small shank ladles about thirteen inches diameter inside after daubing, and of a depth to carry the desired weight of steel. The penetrating heat of steel is greater than that of cast iron, and a heavier ladle daubing is required. Hand ladles require a daubing three-fourths to an inch in thickness and small bull ladles from an inch to an inch and a half in thickness. The daubing should be composed largely of silicon sand, with a binder of fire clay and thoroughly dried before using.

Bottom pouring ladles are only required for heavy castings and are not at all desirable for light castings. When required, they may be purchased from the ladle manufacturers or foundry supply houses at a less cost than they can be made, as can also lip pouring steel ladles.

Heating Ladles.

Ladles for steel should be heated to a red heat just before filling with steel. This is generally done with an oil burner and may be done by inverting the ladle over a stationary burner, or by placing a cover over the ladle and introducing the flame of a portable burner through a hole in the cover. The cupola lighting torch may be used for this purpose. When a number of small bulls are used they may be heated rapidly by a number of burners placed in a row 18 inches apart, and the shank stood on end in front of them. It takes very little time to heat ladles with oil burners; fifteen minutes is sufficient time to bring them up to a good red heat after drying.

Flux for Steel.

For cupola fluxing in melting for steel castings the same flux is used as in melting cast iron, and it is used in the same way. For a ladle flux aluminum is generally used for giving life and fluidity to the steel. This metal is so light that when used in small pieces or lumps it floats upon the surface and is difficult to get into the steel. The best way to use it is in the half-inch round rods; the end of the rod is thrust down into the steel and held there until melted and absorbed by the steel. Another substance used as a flux is Thermit. This is used principally to liven up the steel when too dull for pouring. A can of it suitable for size of the ladle is placed in the end of a taping rod and pushed down into the steel. Its effect is almost instantaneous and the steel becomes hot and fluid; but its effect is not lasting, and the steel should be poured at once to derive the full benefit of it.

Molding Sand.

For steel casting a silica sand of about ninety-six per cent. purity is generally used for both molds and cores. This sand is very friable and a binder is required to hold it in place. For this purpose finely ground fire-clay is mixed with the sand, the mixture wet up with water, or the sand may be wet up with molasses water. Either of these binders admit of the mold being broken up after casting and the sand used over. Any of the core binders, such as oil, flour, dry core compounds, etc., may be used as a binder. It is not necessary that the entire mold should be made of this sand, as only a facing of it may be used with a backing of ordinary molding sand. Before casting, the molds are put in an oven and baked the same as dry sand molds. This is the common practice in steel foundries for heavy castings, and in many of them also for light castings. But it is not absolutely necessary that a dry sand mold should be made for steel castings, although it is a safer mold for large castings. A skin dried mold, faced with a wash of silica flour and molasses water, may be used. This wash, when properly applied with a brush or sprayed on and well dried, gives to the mold a hard, refractory surface that resists the action of steel equally as well as an oven baked mold for small castings. Molds for steel are made in the same way as for iron, and the same precautions must be taken to prevent cutting of the mold, run outs, etc. With a large bottom pour ladle the pressure in molds is very great, and a strong flask and mold are required to stand this pressure. For very small, light castings, such as bench work, the regular green sand mold may be used without drying, but the sand should be worked as dry

as possible. The steel sets so quickly in these castings that the silica flour wash is not necessary.

Flasks.

All molds for steel are made of dry sand except those for bench work, which are made in green sand, and those for small castings, which may be skin dried. The regular foundry flasks may be used for these molds, but must be strong flasks. Those of dry sand are placed in a core oven and baked, and require a metal flask; the sand bakes in these very hard and is difficult to remove, and a sledge is often used upon a flask in removing it, and a very strong flask is required to stand this treatment. They are generally made of cast steel, of from one-half to an inch in thickness, and well flanged and ribbed to make them strong, and well perforated to admit of gas from the mold escaping freely. The rolled steel flasks have been tried for steel casting, but have not proven very satisfactory, as the sledging dents and bends them so that the pins do not fit, and they are not perforated for the escape of gas.

Dry Sand Cores.

All cores used for steel castings are dry sand cores. They are made of the same grade of silica sand as that used for molds. The core binder used should be one that would admit of the core, giving or collapsing as soon as the steel begins to set around it, and admit of a rapid shrinkage of the steel when changing from the molten to a solid state. For the shrinkage of steel is so rapid, and so great at this stage, that a hard, rigid core may cause hot cracks and at a point just below a red heat, cause cold cracks. To reduce such loss to the lowest possible point, cores should be rodded, to give the required strength, soft rammed; and large ones filled with small coke or cinder with only a thin shell of core sand around the outside, so that when they have served their purpose they may give away as soon as the steel begins to contract in cooling. A wash of silica flour and Ceylon graphite wet up with molasses water should be applied to the cores to give a hard outer scale and make the sand peel and leave a clean, smooth hole.

Cracks in Steel Castings.

Cracks in steel castings are of two kinds, and are known as hot and cold cracks. Hot cracks occur when the steel is solidifying in the mold, and are due to shrinkage of the metal at the time of solidification. They present a ragged, torn edge covered with a film of blue oxide, and have the appearance of a tearing

apart of the metal, rather than a crack. Cold cracks take place when the metal is cold and also when below a red heat, in which case they generally show the blue film of oxide. These cracks are generally very small, and at times can only be detected by the ring of the casting when struck by the hammer. These cracks are due to shrinkage and the casting being on a strain. They can only be prevented by changing the pattern or annealing the casting before cooling.

Shrinkage in Steel.

The shrinkage of cast steel is much greater than that of cast iron and also more rapid. One of the greatest dangers met with in steel castings is in the casting being drawn apart by shrinkage when the steel is changing from the molten to a solid state, and the steel is at its lowest point of strength and shrinkage at its highest. At this point a rigid mold or core may cause hot or cold cracks in a casting. The only way to prevent this occurring is to make molds and core as elastic as possible. Another trouble met with is surface and internal shrink holes. The latter are seldom found until the casting is being turned or planed in finishing, when it may be found to be honeycombed with small holes or one or more large ones, having the appearance of blowholes, but are really shrink holes. Numerous small holes are generally due to the steel being poured too dull, and is overcome to a considerable extent in medium weight castings by pouring the steel hot and fluid and by large gates and runners that remain hot and feed up the casting. Shrinkage in heavy castings is controlled by sink heads and churning. It is a matter of dispute whether one large sink head or a number of smaller ones gives the best results. In very light steel castings the metal sets so quick that they require no heavier gates than cast iron. Such a large amount of metal is required for gates and sink heads in steel foundries that the remelt of these alone is from 12 to 40 per cent. of the melt, and the heavier the castings the higher the per cent. of remelt. In making cupola steel castings the same practice must be followed to insure sound castings, as with a high steel mixture. With a low steel mixture shrinkage is not so great and remelt not so heavy. This mixture is made by increasing the per cent. of pig in mixture and for many purposes gives a superior casting to that of a high steel mixture.

Annealing.

All steel castings should be annealed to a greater or less extent to admit of the carbon being broken up and more evenly distributed and the molecules arranging themselves to give the

greatest possible strength to the casting. Also to relieve strain, reduce warpage and remove hard and soft spots in the casting. Small chunky castings retain their heat to so great an extent that annealing of them is not always necessary; but large castings of thin section and very heavy ones should always be annealed to realize the full strength of the steel. The length of time required to anneal depends upon the shape, weight of casting and object in view. If it is only desired to equalize strain in thin and light castings, from one to two hours is a sufficient length of time.

It is the practice in steel casting plants to anneal the castings over night, and if not sufficiently soft to put them in again for a second annealing.

They are also annealed by heating to a temperature of 1800 degrees Fah. and cooling in the open air, and if not sufficiently soft heated again and cooled. I have obtained excellent results in this manner of annealing.

The matter of ladles for steel, heating ladles, flux, molding sand and flasks is something that should be decided upon by the founder as found necessary, for in many cases the gray iron foundry outfit answers every purpose in handling and casting this steel.

Steel Malleables

Steel malleables is a name that has been given to malleables in which the predominating metal in the mixture is steel. Many attempts have been made to make this metal in a reverbratory furnace, but it has been found that only a very small per cent. of steel can be used in a mixture in this furnace for the reason that steel does not malleablize to produce a strong malleable.

But this is not the case with a cupola melted steel mixture, for the steel takes up carbon from the melting fuel, and comes back fully to a white iron that malleablizes readily, and produces a superior malleable to either charcoal or coke white cast iron. This is due to the impurities having been removed from the iron in the steel making process, and the iron having been made a purer metal than either charcoal or coke smelted iron.

This purified iron does not come in contact with impurities when melted in a cupola to so great an extent as iron in its ores, or when smelted from its ores in a blast furnace. A purer iron is therefore obtained from it when melted in a cupola than can be obtained in melting cast iron in a reverbratory, and the quality of the metal is as fully under control as that melted in a reverbratory furnace. These facts have been fully demonstrated in actual malleable practice, and a number of malleable plants have adopted this metal exclusively for their malleables for the reason that the mixture costs less, the melting costs less and a superior quality of metal is obtained.

Advantages of This Metal.

The advantages of this metal are: first, cheapness of mixture; second, reduced cost of melting; third, superior qualities of malleables.

The mixture for this metal contains an average of seventy per cent. steel scrap. There is no demand for this scrap in many parts of the country, and it is selling at the present time as low as five to eight dollars per ton, and in almost any part of the country may be purchased at from two to five dollars per ton below that of standard malleable pig. It will therefore be plainly seen that with the large per cent. of this scrap used in the mixture, the cost of mixture may be reduced from two to five dollars per ton.

The cost of melting in cupola practice, as is well known, is much less than in reverbratory furnace practice. The cost of cupola melting varies with the size of heat, and has been estimated at from seventy-five cents to eighty-six cents per ton of metal melted.

Steel malleables possess greater tensile and transverse strength, the deflection and bending properties are greater, and the softness or rigidity of the metal is completely under control of the operator, by varying the metalloids in the mixture, the same as they are varied in iron mixture to give these results.

Cupola Melted Metal for Malleables.

Seth Boyden, the pioneer of the malleable industry in this country, in 1826 melted all his iron in the cupola, and as late as 1872, when I constructed and managed a malleable plant, all our iron was melted in the cupola, and this was the general practice at that time, only a few of the malleable plants having been equipped with reverbratory furnaces for melting.

But the present generation of malleable men have been brought up to the reverbratory furnace melting, and almost universally condemn cupola melted metal for malleables, which is probably due more to hearsay than to actual experience with cupola melted metal.

If iron for malleables could be melted in cupolas in early days, when there was neither system nor scientific principles employed in either construction or management, it certainly can be melted today with our scientifically constructed cupolas and management.

One of the great objections of furnace men to the cupola is that the metal cannot be tested before it is cast, and cannot be doctored before casting if not right. This may be necessary for iron malleables, but is not the case with steel malleables, for the mixture determines the quality of the metal, and no doctoring is necessary, and this metal is being melted in a number of malleable plants at the present time, and better malleables produced than is

being made from furnace melted metal after testing and doctoring.

Malleables Mixtures.

In the making of mixtures for malleables, the standard malleable pig or machined cast Bessemer is generally used.

This pig is used for the purpose of giving fluidity to the molten metal, and promotes the absorption of carbon by the steel to an extent that will bring it fully back to a white iron with all the carbon in the combined state. To obtain this result, the silicon must be sufficiently high to promote the absorption of carbon to this extent and no farther.

The per cent. of steel placed in mixtures has been varied from forty to eighty-six per cent., and different per cents. have been found to give the best results to various lines of casting, but for the general line of malleables the best results have been obtained with about seventy per cent steel. With this per cent, a tensile strength above 65,000 lbs. has been obtained.

The following mixture analysis and tests have been furnished by a large malleable plant in which the principal output is plow and agricultural malleables, for which this mixture is being regularly melted.

Machine cast Bessemer, silicon, .80 to 1.25; phosphorus, .15 to .30; manganese, .80 to 1.25; sulphur, .030 to .040; steel scrap, 70 per cent. Producing the following analysis in castings: silicon, 0.55; sulphur, 0.15; phosphorus, 0.177; manganese, 0.31; combined carbon, 0.77; graphite carbon, 0.53.

Physical tests as follows: Diameter of test bar, .620; breaking strain, 19,200; ultimate strength, 63,570 lbs. These tests show the average of daily tests made for a month.

Another mixture that has proven very satisfactory was made with the following analysis: Machined cast coke iron, silicon, .60 to 1.00; sulphur, .05 and under; phosphorus, .30 and under; manganese, .50 to 1.00; steep scrap, 70 per cent; manganese preferred, about .60.

The analysis of pig is varied to suit the thickness of sections and the per cent. of steel maintained at a high point, seventy per cent. having been found to give the best results, but it may be varied to suit the thickness of section, and excellent results have been obtained with sixty to eighty per cent. steel in mixture.

Another mixture that has just been tried and proven satisfactory in a sixteen-day test and is still being used is as follows:

Machine cast Bessemer, silicon, .89; sulphur, .033; phosphorus, .18; manganese, .79; steel scrap, 86 per cent. This mixture is being made from the blast furnace analysis, furnished with the car of pig, which has proven very satisfactory.

All the above mixtures were made upon the theory that the gates and remelt from heat of the previous day contain exactly the same percentages of the various metalloids used in the mixture upon that day less ten per cent. loss in melting. This theory has been disputed by various chemists and founders, but a little reflection should convince them that the analysis of the heat from which this metal was made is the only data they have from which an accurate mixture can be made without an analysis of this scrap which invariably shows this result if the metal has been properly melted.

Silicon.

In the making of this metal for annealing, silicon is an important factor. This must be sufficiently high to promote the absorption of carbon to a point that converts it fully back to white iron; if this is not done, the casting will contain patches of steel, which do not malleablize, and an uneven malleable is produced. These patches may be seen in the fresh fracture of a test bar with the naked eye and in light castings with the microscope, and this point should be carefully watched that the full strength of the malleable may be realized.

In case they are found, the remedy is to increase the silicon to a point that will increase the absorption of carbon to an extent that gives an even crystalline structure in the annealed casting. I have found it better to do this than to reduce the per cent. of steel in the mixture, although in some cases it may be advisable to reduce the steel in place of increasing the silicon.

Sulphur.

In case of sulphur running too high, its effect, both in the white metal and in the malleable, may be offset by an increase in the silicon, but care must be taken to not increase it to an extent that will produce graphite carbon in the metal to an extent that will destroy the annealing properties of the metal and reduce its strength.

Manganese.

The effect of high manganese in semi-steel is to destroy the life of the metal and also to cause dirty castings. These results have not been met with in steel malleables to so great an extent

as in semi-steel, which is probably due to the standard pig for malleables not running so high in manganese, as that of gray iron casting pig, but no doubt would be found if the manganese was excessively high. In case it is met with, the remedy would be to reduce the manganese from .40 to .60. This has been found to give the best results.

Carbon.

The carbon contents of this metal is controlled by the silicon, which must only be sufficient to carbonize the steel to an extent of converting it fully back to a white iron, with all or nearly all of the carbon in a combined state.

Coke

The coke used in melting must be a low sulphur hard coke. The Western Solvay bi-product coke has proven very satisfactory in melting this metal, but owing to less care being taken in the selection of coal, and the coking process, the Syracuse Solvay coke has not proven so satisfactory. There are also other cokes that have given very satisfactory results, and any of the low sulphur hard cokes may be used for melting.

Melting.

In the melting of this metal for malleables, care must be taken not to melt the mixture so low in the cupola as to be struck by the blast and oxidized in melting, or melted so high as to be roasted and burned before melting. To avoid this occurring, my instructions for charging and melting gray iron, semi-steel and cupola steel should be carefully studied, and the metal melted hot, and with an even temperature throughout the heat, and as fast as the cupola is able to melt it. This can only be done by the use of a proper amount of fuel, and even charging of the stock. In all cases the dividing up of the stock into very small charges should be avoided, as the tendency to oxidize the iron, in this method of charging, is very great.